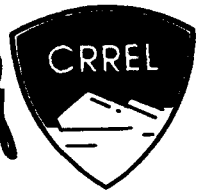


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# **Modeling Ice Passage Through an Auxiliary Lock Chamber With a Submergible Lift Gate**

Jon Zufelt, John Rand and Gordon Gooch

June 1993

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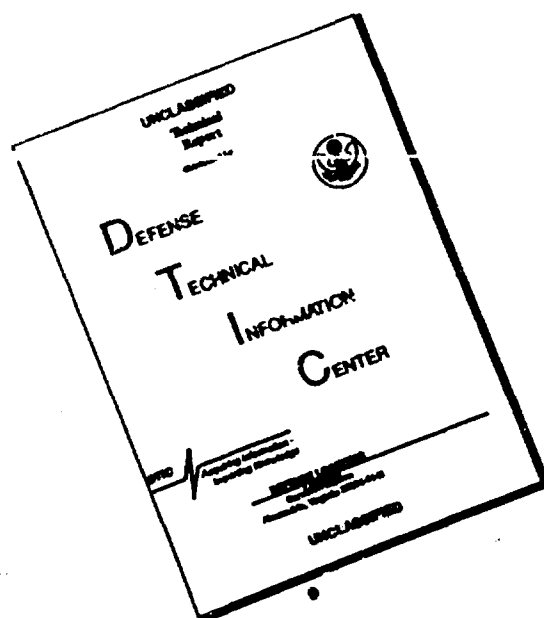
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**Abstract**

River ice from the Des Moines and Fox Rivers combines with that of the Mississippi during spring breakup, resulting in massive ice accumulations upstream of Lock and Dam 20 on the Mississippi River. The accumulations in the upper lock approach area cause considerable delays to navigation, as ice must be passed through the lock chamber to clear the approach. A physical model study was conducted to determine the effects of using the existing auxiliary lock chamber to pass ice. The auxiliary lock chamber was fitted with a submergible lift gate at its upstream end that could be lowered to pass ice and clear the upper lock approach area. Model tests were conducted with real and plastic ice material to simulate the brash ice conditions encountered during low-flow prototype winter conditions. The submergible lift gate worked well in clearing ice accumulations from the upper lock approach. It was necessary to disturb the accumulation and keep it from refreezing by simulating towboat movement or high volume point source air bubblers to thoroughly clear the approach area.

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380-89a, *Standard Practice for Use of the International System of Units*, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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# Special Report 93-15



**US Army Corps  
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Cold Regions Research &  
Engineering Laboratory

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Jon Zufelt, John Rand and Gordon Gooch

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## PREFACE

This report was prepared by Jon Zufelt, Research Hydraulic Engineer; John Rand, Research General Engineer; and Gordon Gooch, Civil Engineering Technician, of the Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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# Modeling Ice Passage Through an Auxiliary Lock Chamber With a Submergible Lift Gate

JON ZUFELT, JOHN RAND, AND GORDON GOOCH

## INTRODUCTION

This report examines ice passage at Lock and Dam 20 on the Mississippi River using a scale physical model. The model study was conducted to determine the effectiveness of using a submergible lift gate to pass ice from the upper lock approach area through the auxiliary lock and downstream.

Lock and Dam 20 is one of the structures making up the Inland Waterway Navigation System of the Upper Mississippi River Basin. It is located at River Mile 343.2 (miles upstream from the mouth of the Ohio River) on the Mississippi River near the city of Canton, Missouri (Figure 1). The Lock and Dam 20 pool extends approximately 21 miles (34 km) upstream to Lock and Dam 19 at Keokuk, Iowa. Construction of Lock and Dam 20 began in November, 1932, and was completed in November, 1935. The facility was placed into operation on 9 June 1936. The structure is owned and operated by the Rock Island District of the U.S. Army Corps of Engineers.

The structure actually contains two navigation locks. The main lock is located on the Missouri shore and is 110 ft (33.5 m) wide and 600 ft (183 m) long. The auxiliary lock was designed to be 110 ft wide by 360 ft (33.5 by 110 m) long but was never completed (Figure 2). The main lock is equipped with miter gates at its upstream and downstream ends, but the auxiliary lock was only equipped with an upstream miter gate. The maximum lift through the lock is 10.5 ft (3.2 m). The river guard wall upstream of the locks is actually a series of sheet pile 'cells' with a bridge superstructure built on top of them. The superstructure extends below the water surface and thus prevents ice passage from the upper approach area through the cells. During the 1940s the unobstructed space between the first cell and the riverward auxiliary lockwall was increased from 5.0 to 23.0 ft (1.5 to 7 m) in an effort to clear debris and ice from the lock

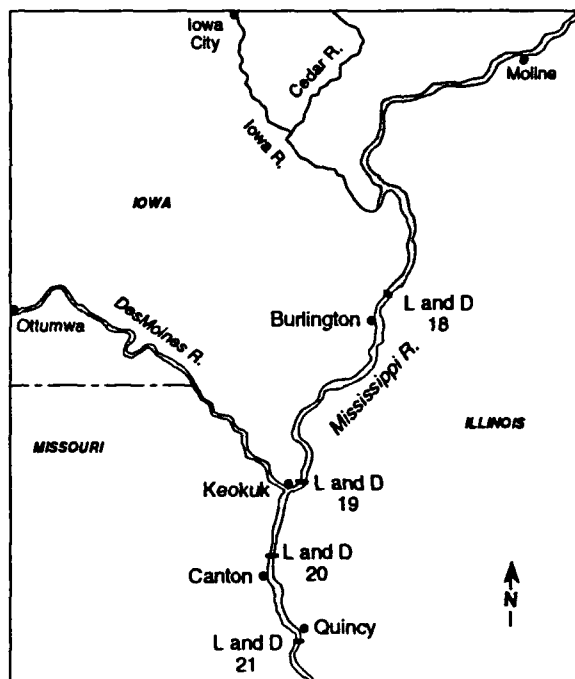


Figure 1. Location map of Lock and Dam 20, Mississippi River.

approach area. While this has proved somewhat helpful for minor debris accumulations, it has not been effective for ice.

The dam has a total length of 2294 ft (700 m), which consists of 150 ft (45.7 m) of non-overflow earthen dike on the Illinois shore and 2144 ft (653.5 m) of gated structure between the earthen dike and the locks. There are 43 gates in the dam: 40 are tainter gates and three are roller gates. The three roller gates are nonsubmergible; they are 20 ft high and 60 ft wide (6.1 by 18.3 m) and are located near midchannel. The 40 tainter gates measure 20 ft high by 40 ft wide (6.1

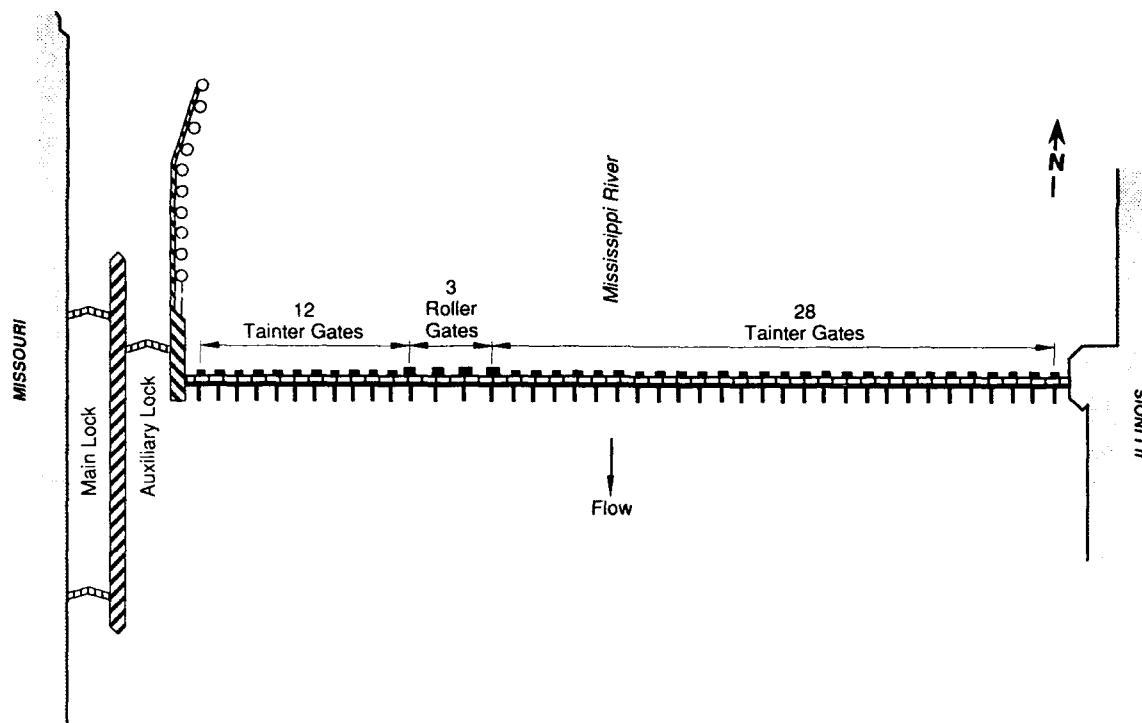


Figure 2. Plan view of Lock and Dam 20, Mississippi River.

by 12.2 m). Gates 1, 2, 17, 18, 42, and 43 are also capable of being submerged 3 ft (0.9 m) below the normal crest elevation of 480.0 ft (146.3 m). The layout of the gates is shown in Figure 2.

The normal navigation season for Lock and Dam 20 is February through December, but lockages do occur all year. The average number of tows transiting the lock each month for the years 1990–1992 are given in Table 1. River traffic generally declines through December as the river freezes over and remains very low through January and February. During these marginal times, the entire river may be covered with ice except for a ship track cut through the ice corresponding to the 9-ft-(2.7-m-) deep navigation channel. Traffic picks up again during March and remains high through spring, summer, and fall.

Ice problems at Lock and Dam 20 are twofold. During the period when the river is partially covered or when only a ship track exists in an ice-covered river, brash ice flowing downstream is pushed into the lock approach by downbound tows. This ice can fill the entire approach area and must be locked through just as a tow and barges would be. Another method of clearing the lock approach is to divert the incoming ice away from the approach and toward the dam, where it can be passed over or under the dam gates. During most of the winter, however, the

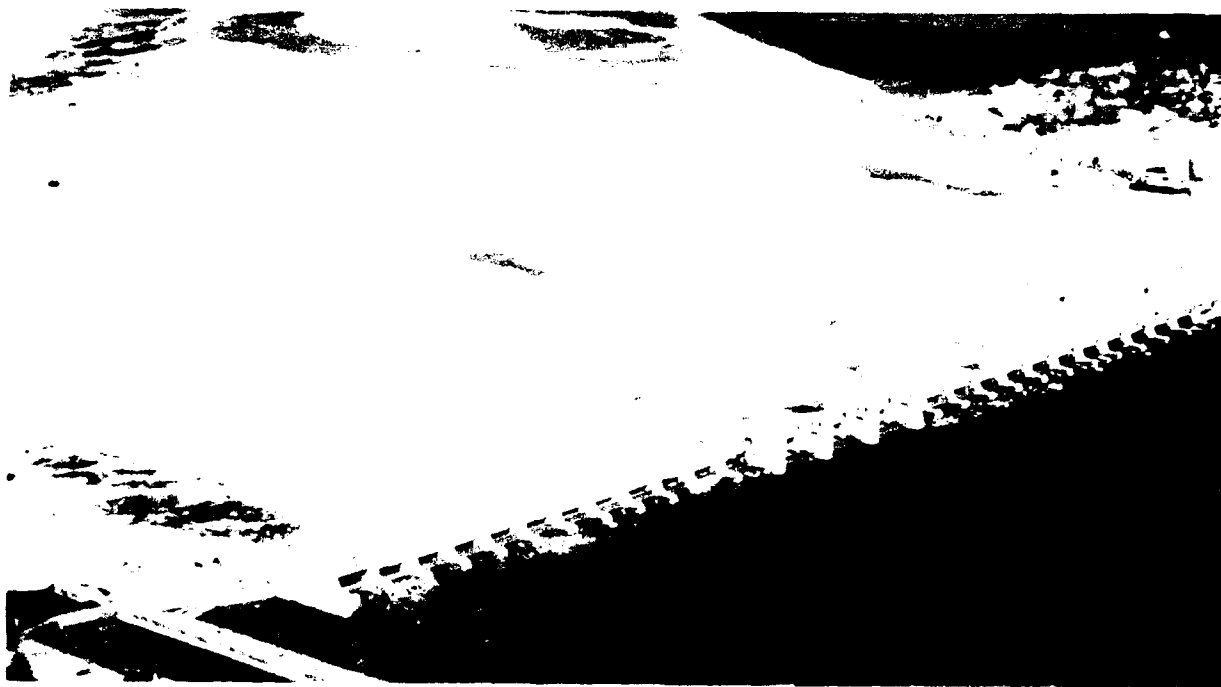
discharge in the river is very low. This results in small dam gate openings that are insufficient to pass ice. Towboats sometimes use their propeller wash to direct ice out of and away from the lock approach and toward the dam gates. To assist ice movement, the towboats are often requested to keep a section of the ice cover broken from the approach area to the dam gates.

As spring approaches and temperatures rise, the ice cover on the river begins to break up. Higher discharges are often associated with the spring breakup

Table 1. Average monthly lockages for 1990–1992.

Month	Number of lockages
January	12
February	43
March	340
April	419
May	464
June	465
July	533
August	524
September	401
October	401
November	361
December	143





*Figure 3. Severe ice jam at Lock and Dam 20, Mississippi River.*

period and thus necessitate larger gate openings at the dam that facilitates ice passage. Many of the tributaries also break up at nearly the same time as the Mississippi River, causing large ice runs that move downriver. The Des Moines River is a large tributary that enters the Mississippi just downstream of Lock and Dam 19. The Des Moines often breaks up and runs into the Mississippi, causing very severe accumulations and jams at Lock and Dam 20 (Figure 3). These large amounts of ice can become grounded in the pool upstream of the dam, cutting off navigation for several days until the jam can be cleared.

Ice problems such as these are not unique, as evidenced by the response to a survey on ice problems at navigation facilities conducted by CRREL (Zufelt and Calkins 1985). Similar problems exist at many locations on the Mississippi, Ohio, Illinois, and Monongahela rivers. These facilities have devised many ways to deal with the problems of ice in the upper lock approach and ice passage through navigation dams. Submergible tainter gates have been used with success at several locations on the Illinois Waterway. Submergible tainter and submergible roller gates have been used on the Mississippi River. On the Ohio and Monongahela Rivers, facilities have modified their upstream emergency lock closure

bulkheads to act as overflow weirs. These bulkheads are placed in the auxiliary lock chamber and both the upper and lower lock gates are opened, with the result that the ice passes over the bulkhead, through the lock, and downstream.

The Rock Island District (RID) contacted the Ice Engineering Research Branch of CRREL following the particularly troublesome winter season of 1990-91, which was plagued with ice problems at Lock and Dam 20. RID was interested in improving ice passage at the facility, particularly during the winter low-discharge periods. The Ice Engineering Research Branch had recently completed a physical model study of ice passage problems at Starved Rock Lock and Dam on the Illinois Waterway for RID (Gooch et al. 1990). In that study, CRREL recommended the installation of two submergible tainter gates to increase ice passage through the dam and reduce ice accumulations in the upper lock approach. Since the auxiliary lock of Lock and Dam 20 was never completed and was within the upper approach area, it appeared that passing ice through the auxiliary lock chamber would be very effective in clearing the upper approach. It was decided to physically model a vertical gate structure at the upstream end of the auxiliary lock that could be submerged to pass ice from the upper lock approach.

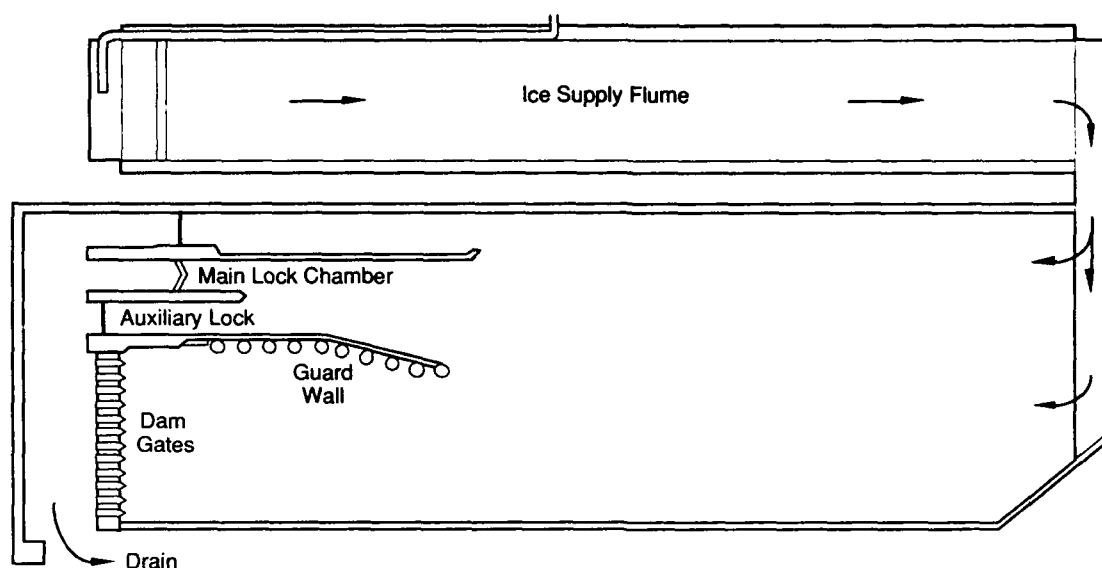


Figure 4. Plan view of IEF Research Area showing model of Lock and Dam 20 as constructed.

## MODEL DESIGN AND CONSTRUCTION

The physical model of Lock and Dam 20 was constructed in the refrigerated research area of the Ice Engineering Facility at the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL). The refrigerated research area is a large, unobstructed room measuring 80 by 160 ft (24.4 by 48.8 m) with a refrigeration system capable of lowering the air temperature in the room to  $-10^{\circ}\text{F}$  ( $-18^{\circ}\text{C}$ ). Water can be delivered from a 60,000-gallon ( $230\text{-m}^3$ ) sump through a variety of pipelines and pumps to the model area at discharges up to  $5\text{ ft}^3/\text{s}$  ( $0.14\text{ m}^3/\text{s}$ ). A large ice supply flume measuring 16 ft wide, 140 ft long, and 1.5 ft deep (4.7 by 42.7 by 0.46 m) is located along one wall of the research area and can be used to further cool the water coming into a model or to form ice sheets that can then be broken up and fed into a model. A trough is located along the opposite wall to return the water to the sump. An overhead crane system capable of bidirectional movement provides access to any area of the model without the need for scaffolding, catwalks, or their supports, which would obstruct flow or ice movement in the model. Figure 4 shows a plan view of the research area with the Lock and Dam 20 model as constructed.

Since the main objective of the study was to determine the effectiveness of the submergible gate and ice movement in the upper lock approach area where vortices and other three-dimensional flow effects

were possible, it was decided to construct an undistorted model in which the horizontal and vertical scales are equal. The Lock and Dam 20 model was therefore designed and constructed as an undistorted, sectional, Froude scale model, at a scale of 1:25.

The scale of a model is represented by the ratios of its horizontal (H) and vertical (V) lengths to that of the prototype

$$(L_H)_R = \frac{(L_H)_M}{(L_H)_P} \quad \text{and} \quad (L_V)_R = \frac{(L_V)_M}{(L_V)_P} \quad (1)$$

The subscripts R, P, and M refer to ratio, prototype, and model, respectively. The vertical length ratio is usually equal to the depth ratio. For an undistorted model,  $(L_H)_R = (L_V)_R = L_R$  and the model is characterized simply by the length ratio  $L_R$ . The acceleration due to gravity is the same for both the prototype and the model, resulting in  $g_R = 1$ .

Froude model similarity requires that the Froude number of the model and prototype be equal or that their ratio be equal to unity:

$$Fr_R = \frac{Fr_M}{Fr_P} = \frac{V_R}{\sqrt{g_R h_R}} = 1 \quad (2)$$

where  $Fr$  = the Froude number

$V$  = water velocity

$g$  = acceleration due to gravity

$h$  = water depth.

Substituting  $h_R = L_R$  and  $g_R = 1$  into eq 2 above, the velocity and discharge scales then become

$$V_R = \sqrt{h_R} = \sqrt{L_R} \quad (3)$$

$$Q_R = A_R V_R = L_R^2 V_R = L_R^{5/2} \quad (4)$$

where  $A_R$  is the area ratio.

The scale chosen for a physical model is bounded on the high side (large model) by the space and pumping capacity available as well as cost. Minimum scales (small models) are dependent on the measurement accuracy required and the need to avoid viscous and surface tension effects. There was an opportunity for additional cost savings for this model study since the Starved Rock Lock and Dam model study had just been completed and the model had not yet been demolished. The Starved Rock Lock and Dam physical model was a 1:25 scale undistorted physical model that included the lock structure, a section of ungated dam, and three of the 10 tainter gates (Gooch et al. 1990). The Starved Rock lock chamber was also the same width as the main lock chamber and was located in a similar position to the dam as Lock and Dam 20. By choosing a scale of 1:25 for the Lock and Dam 20 physical model, it was pos-

sible to use the existing (Starved Rock) model pump and piping system, inlet and outlet works, lock chamber, lock gates, and filling ports, and the dam sill. This saved a considerable amount of time, and the cost for demolition of the old model and construction of the new model was reduced by 50%.

By choosing this length scale, however, the width of the model was limited to the right bank, lock chambers, and the first 13 of the 44 gates on the dam. This included the first 12 tainter gates and the first roller gate. As mentioned above, the main purpose of the model study was to investigate ice passage during periods of low flow during winter. Under these conditions, the river is typically frozen over completely except for a continually rebroken ship track near the right bank leading into the lock chamber. The winter discharge to be modeled was approximately 39,000 ft<sup>3</sup>/s (1100 m<sup>3</sup>/s) and, at this discharge level, the gate operating schedule calls for gates 1-12, 17, and 18 to be opened 3 ft (91 cm) and gate 19 to be opened 2 ft (60 cm). Since the main area of interest was the lock approach area and the first few tainter gates, it was not necessary to model the entire dam.

Detailed hydrographic surveys provided the data necessary for modeling the riverbed upstream from the dam. Construction drawings provided informa-

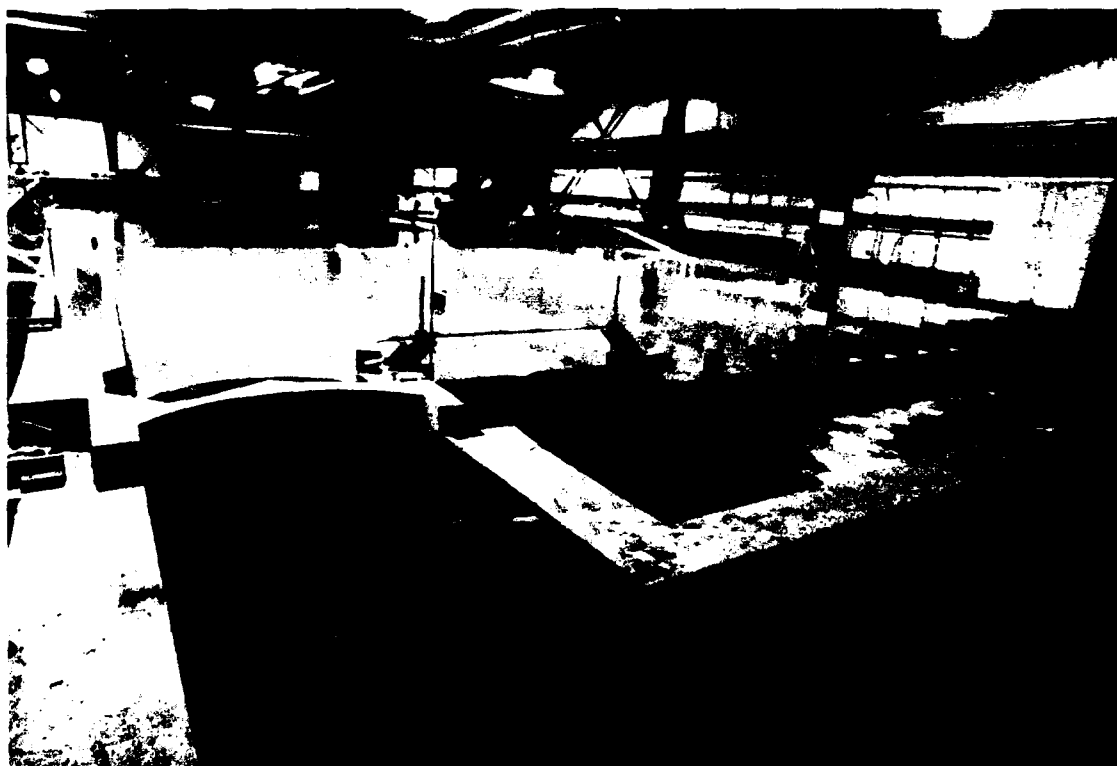


Figure 5. View looking upstream at the main and auxiliary lock chambers and submersible lift gate.



Figure 6. View of the completed model looking downstream at the approach area and dam.

tion for the auxiliary lock, sheet pile cells, and dam gates. Model construction entailed the fabrication and placement of plywood templates at 4-ft (1.2 m) spacing upstream of the lock and dam. The area between the templates was then filled with sand and smoothed before being covered with a 3-in. (76-mm) thick concrete cap. The sheet pile cells, auxiliary lock structure, and dam piers were fabricated with poured concrete. The dam tainter gates were constructed of wood and plastic. Since the model tests were to be conducted at a single, low winter discharge, the dam gates were constructed as non-operable overflow weirs rather than operable undertlow-type gates. The vertical lift gate in the auxiliary lock chamber was simulated with a sharp-crested aluminum plate that could be raised and lowered. Figure 5 shows the main and auxiliary lock chambers and the submersible lift gate looking upstream at the approach area. Figure 6 shows the completed model looking downstream at the approach area and dam.

#### MODEL CALIBRATION

The model was calibrated by matching a detailed set of prototype velocity measurements taken during low flow, open water conditions during late October, 1990. The locations of the velocity measurements are shown in Figure 7; they included the upper lock approach and the spaces between the cells of the river guard wall

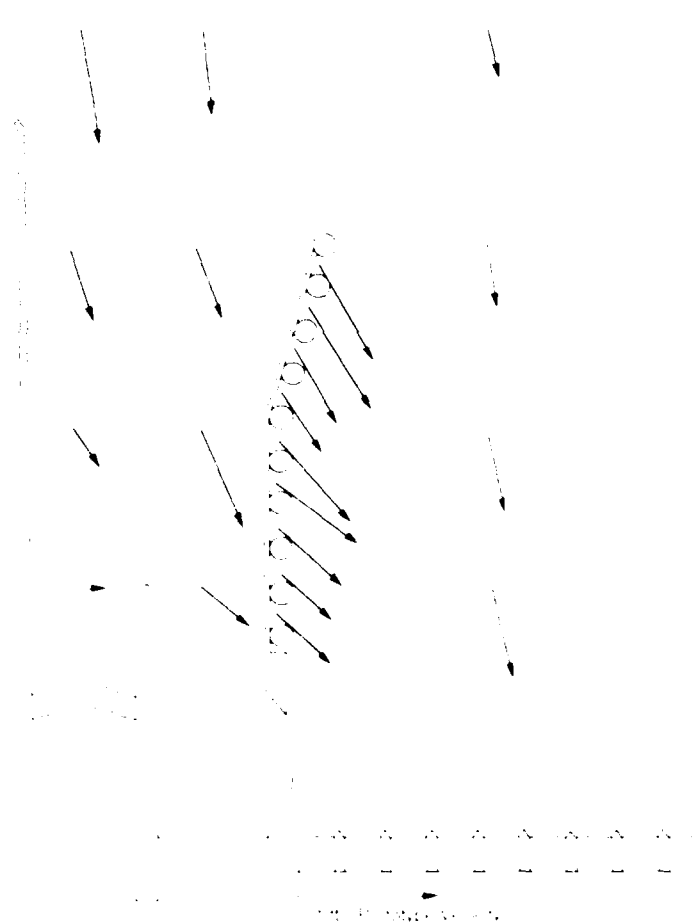


Figure 7. Prototype velocity measurements taken October, 1990.

The prototype velocities were taken at approximately 1 ft (30 cm) below the water surface, to simulate the velocity of free drifting ice. For the locations between the cells, the depth of measurement was increased

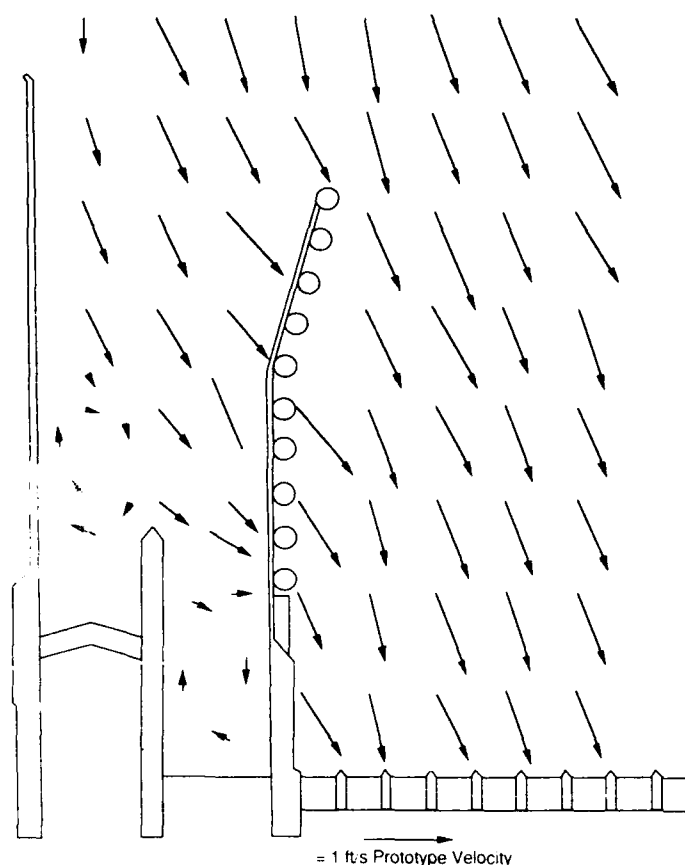


Figure 8. Velocity vector plot of flow configuration in the model following calibration.

to 6 ft (1.8 m) due to the blockage of surface flow by the submerged wall connecting the cells. The discharge in the river during the velocity measurements averaged 37,500 ft<sup>3</sup>/s (1060 m<sup>3</sup>/s), with the upper pool elevation at 479.75 ft (146.2 m) and the lower pool elevation at 471.8 ft (143.8 m).

If the entire width of the river had been modeled, it can be seen from eq 4 and the model scale of 1:25 that the model discharge to simulate 37,500 ft<sup>3</sup>/s (1060 m<sup>3</sup>/s) in the prototype would be 12 ft<sup>3</sup>/s or approximately 5400 gal/min (0.33 m<sup>3</sup>/s). This value is well above the pumping capacity of the research area. By reducing the model width to the first 13 gates of the dam, it was possible to reduce the pumping requirements. We wanted to run several tests with real ice in the model, but at large pump discharges a considerable amount of heat is added to the water, which quickly melts the ice in the model and affects the results. The maximum pumping rate possible to avoid melting the ice in the model is approximately 1350 gal/min (0.085 m<sup>3</sup>/s). This pumping rate would require closing the outer gates with only the first six gates of the dam open. Since the primary interest was

ice movement in the lock approach area, we decided to calibrate the model by closely matching the prototype velocities inside and immediately outside of the lock approach area. The flow was further adjusted by placing roughness elements and flow alignment structures at the model inlet and on the bed immediately upstream of the lock approach. Velocities were matched within 10% for all the calibration locations except for the two points immediately upstream of the main lock, where a large eddy developed in the model. In general, the flow approaches the lock parallel to the shore and is diverted toward the dam, accelerating as it flows through the openings between the cells. It then passes through the dam in a nearly normal direction. The general flow configuration is presented in Figure 8 as a velocity vector plot.

Water level in the upper pool of the model was measured by point gauges and the model discharge by an in-line flow meter. Two-dimensional velocities were measured using a Marsh McBirney electromagnetic flow meter oriented to the *x-y* plane of the overhead crane system. Still photography and video coverage were also used to document the model calibration and testing.

## SUBMERGIBLE GATE HYDRAULICS

Experience at other lock and dam facilities has shown that submersible gates can satisfactorily pass brash ice when the submergence is at least equal to 1.5 times the ice piece thickness. Thermally grown sheet ice thickness would not be expected to be more than 2 ft (61 cm) for the upper Mississippi River in the vicinity of Lock and Dam 20, but frazil deposition could result in significantly thicker ice. The Rock Island District suggested that the model gate be operable up to submergences of 8 ft (2.4 m). The prototype submersible lift gate would be located in the auxiliary lock chamber upstream from the upper miter gate and would be either a sharp-crested or ogee-crest gate; it would allow ice passage by submerging the crest below the upstream pool elevation. The model gate was constructed as a sharp-crested weir that spanned the entire width of the auxiliary lock or 110-ft (33.5-m) prototype. The discharge over the model gate is given by the weir equation as:

$$Q = 2/3 BC_d \sqrt{2gH}^{3/2} \quad (5)$$

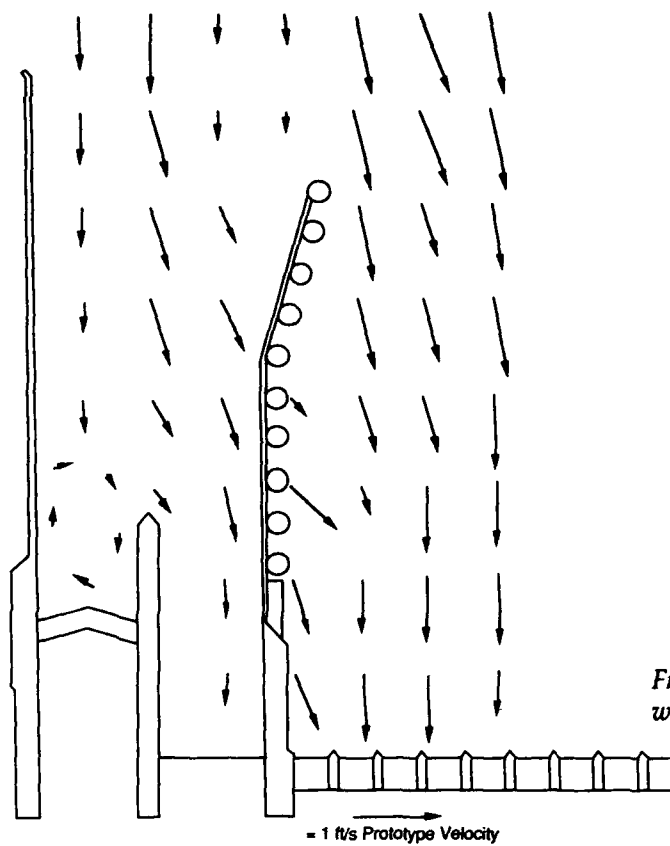


Figure 9. Velocity vector plot for open water conditions with a lift gate submergence of 1 ft.

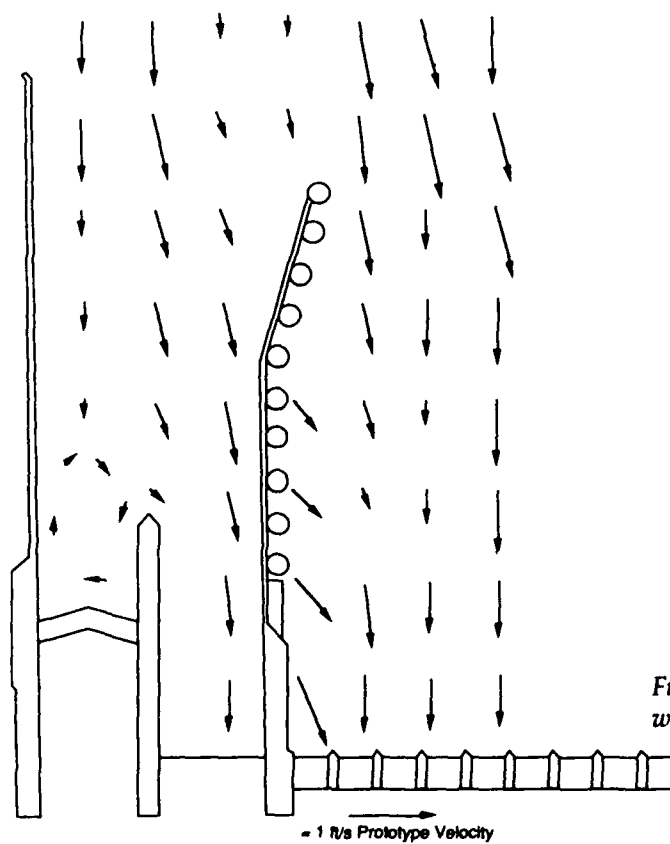


Figure 10. Velocity vector plot for open water conditions with a lift gate submergence of 2 ft.

where  $Q$  = discharge

$B$  = width

$C_d$  = weir coefficient of 0.69

$g$  = acceleration due to gravity

$H$  = submergence of the weir.

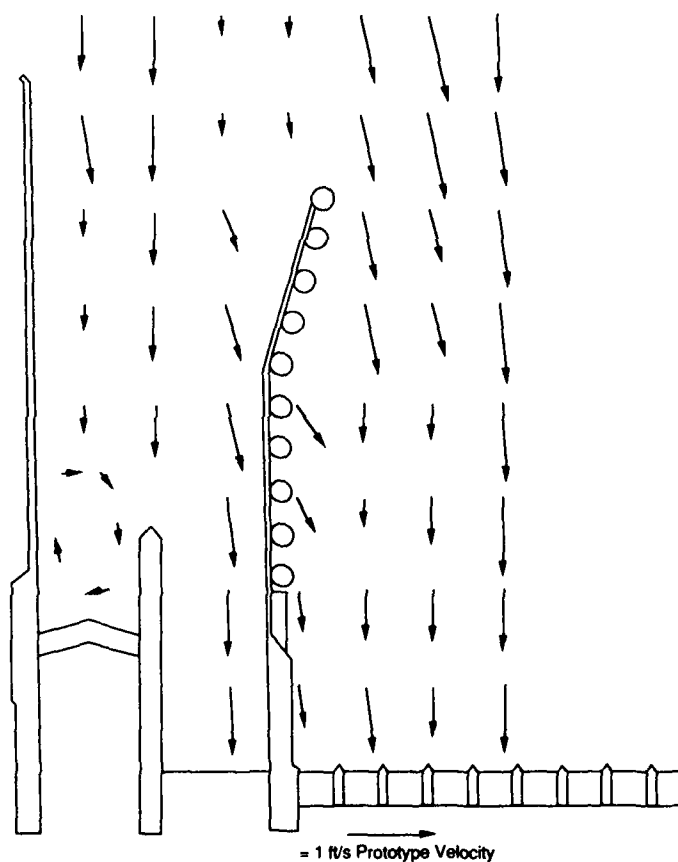
To maintain the upper pool at elevation 480.0 when the prototype submergible lift gate is lowered, it would be necessary to partially or completely close one or more of the prototype dam tainter gates. The model dam gates were constructed as sharp-crested weirs that could be partially or completely blocked over their width to simulate tainter gate closure. It was assumed that the lock operator would choose to close the dam tainter gates closest to the lock, so

this was also done for the model. Using eq 5 above, the discharges at gate submergences of 1, 2, and 3 ft were calculated, along with the amount of closure necessary for gates 1 and 2 on the dam. These are given in Table 2.

Detailed velocity measurements were made in the model for open-water lift gate submergences of 1, 2, and 3 ft for comparison against existing conditions. These are presented in Figures 9 through 11. It can be seen from these figures that lowering the submergible lift gate eliminates the eddy in front of the auxiliary lock chamber, reduces the size of the eddy in front of the main lock chamber and also increases the velocity of flow through the lock approach. The flow coming into the lock approach passes through

**Table 2. Model submergible lift gate hydraulics.**

Gate submergence (prototype ft)	Model discharge (gal/min)	Model discharge (m <sup>3</sup> /s)	Closure of dam gate 1 (%)	Closure of dam gate 2 (%)
1	60	0.038	0	28
2	165	0.010	67	0
3	300	0.019	100	28



**Figure 11. Velocity vector plot for open water conditions with a lift gate submergence of 3 ft.**

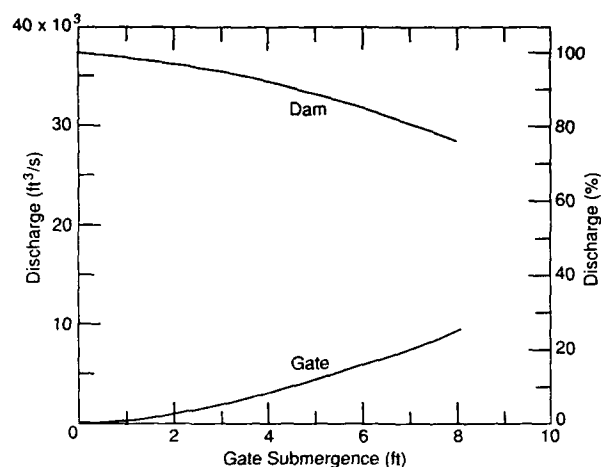


Figure 12. Percentage of total river flow passing through auxiliary lock chamber vs. vertical lift gate submergence.

the auxiliary lock instead of between the cells of the river guard wall. Figure 12 shows the percentage of the total river flow of 37,500 ft<sup>3</sup>/s (1060 m<sup>3</sup>/s) that would be passing through the auxiliary lock vs. the dam gates at lift gate submergences up to 8 ft.

### MODEL TESTING PROGRAM

The velocity of flow through the upper lock approach area is increased by lowering the submergible lift gate. To determine if ice passage is also increased, several tests were conducted using both real and plastic ice materials.

For these tests, the upper lock approach area was filled with ice material. The submergible lift gate was

then lowered, the appropriate closures were made at the first two dam tainter gates, and the model was observed to determine if the ice would pass through the auxiliary lock, thereby clearing the upper lock approach. Tests were also run in which ice was fed into the clear approach area to see if ice arches would form. For all tests, the prototype discharge was held constant at 37,500 ft<sup>3</sup>/s (1060 m<sup>3</sup>/s) with an upper pool elevation of 480.0 ft. Variables for the testing program were the type and size of ice, the submergible lift gate setting, and methods of disturbing the ice cover to reduce refreezing of the brash ice accumulation. Table 3 presents the testing matrix.

Three types of ice were used in the testing: plastic blocks, plastic beads, and real ice. The plastic ice materials are formed of polyethylene with a specific gravity of 0.92. The dimensions of the blocks are 4 in. by 4 in. by 1/4 in. thick (34 by 34 by 6.3 mm), which simulates prototype ice floes 8 ft (2.4 m) on a side and 6 in. (15 cm) thick. The beads are approximately cylindrical in shape with a diameter and length of 3–4 mm or a prototype size of 4 in. (100 mm), simulating brash ice. The real ice was formed in the ice supply flume and then broken into random-sized pieces generally ranging in size from 2 to 9 in. (51 to 229 mm) or prototype sizes of 4 to 20 ft (1.2 to 6.1 m). Thicknesses ranged from 0.5 to 1.5 in. (13 to 38 mm) or prototype thicknesses of 1 to 3 ft (30 to 90 cm). During tests with real ice, the air and water temperature were kept near freezing to prevent excessive melting or refreezing of the ice over time.

Typically, the real ice would arch across the opening of the upper lock approach. Three methods of disturbing the ice cover or accumulation in the upper lock approach were used:

Table 3. Testing matrix.

Test no.	Ice type	Ice thickness, prototype ft (m)		Ice size, prototype ft (m)		Gate setting, prototype ft (m)		Disturbance method
1	beads	0.3	(10)	0.3	(10)	1.0	(0.3)	none
2	real	0.5	(15.2)	4–8	(12.2–24.3)	3.0	(0.9)	none
3	real	1.5	(45.7)	10–20	(30.5–61)	3.0	(0.9)	barge
4	blocks	0.5	(15.2)	8	(24.3)	3.0	(0.9)	none
4A	beads	0.3	(10)	0.3	(10)	3.0	(0.9)	none
5	real	1.0	(30.5)	4–8	(12.2–24.3)	3.0	(0.9)	manual
6	real	1.0	(30.5)	10–20	(30.5–61)	3.0	(0.9)	barge
7	real	0.5	(15.2)	8–12	(24.3–36.6)	3.0	(0.9)	manual
8	beads	0.3	(10)	0.3	(10)	3.0	(0.9)	none
9	blocks	0.5	(15.2)	8	(24.3)	3.0	(0.9)	none
10	real	1.0	(30.5)	sheet		3.0	(0.9)	none
11	real	0.57	(17.4)	8–12	(24.3–36.6)	3.0	(0.9)	barge
12	real	0.82	(25)	8–12	(24.3–36.6)	3.0	(0.9)	bubbler
13	real	0.82	(25)	8–12	(24.3–36.6)	3.0	(0.9)	bubbler
14	real	0.82	(25)	8–12	(24.3–36.6)	8.0	(24.3)	bubbler



1) A model barge constructed at the model scale was pulled or pushed through the arched accumulation.

2) The accumulation was manually disturbed by gently moving a few of the ice pieces at the center of the arch with a pole.

3) A line bubbler and two point-source bubblers were installed on the bed of the model and operated to continually disturb the arch.

Following the bead tests, minor amounts of plastic beads remained in the model that were then frozen into the sheet ice cover grown for the real ice tests. The effects of those beads on the outcome of the real ice tests are negligible.

Test 10 was conducted with a sheet ice cover over the entire model to determine the effect of an ice cover on the water velocity. Small holes were made in the ice cover, and velocity was measured at a prototype depth of 3.0 ft (90 cm).

## RESULTS

The three model ice materials responded differently for several reasons. The beads are small, simulating prototype ice that would be about the size of brash ice or smaller. This ice would be expected to pass easily through the auxiliary lock and over the submergible gate. The beads did pass through the upper approach easily for all gate settings, even the 1-ft (30.5-cm) submergence test. The beads are also cohesionless, which reduces the chances that arches would form in the model. The plastic ice blocks simulated larger ice floes 8 ft (2.4 m) on a side. Although the larger size facilitates arching, the blocks are also cohesionless and regular in shape, which inhibits arching. The real ice consistently formed arches in the upper approach. Their irregular shapes allowed the ice pieces to "key" into each other more easily than did the square plastic blocks. Since air temperatures in the research area were kept near freezing, the real ice pieces tended to freeze together and had to be rebroken before the start of each test.

The effects of the lift gate submergence on the ice movement in the upper approach was minor except very close to the gate itself. Preliminary tests showed that a submergence greater than 1.0 ft (30.5 cm) would be necessary for the real ice tests, as the larger and thicker ice pieces would lodge on the gate.

The 3.0-ft submergence was chosen as a typical prototype setting as this would be able to pass ice up to 2.0 ft (61 cm) thick easily. Midwinter tailwater elevations require gate settings of 3.0 ft (90.5 cm) or less on the dam tainter gates in order to prevent scour. It was assumed that similar limits would exist downstream of the submergible lift gate. The gate was submerged to 8.0 ft (2.4 m) prototype to assess its effectiveness in dislodging ice arches that formed in the upper approach. The increase in velocity through the approach was not sufficient to dislodge the arches.

The ice arches that formed in the upper approach were primarily located just upstream of the entrance into the auxiliary lock, extending from the tip of the bullnose or midlock wall to the river guard wall (Figure 13). In two instances, a secondary arch formed across the entire approach area at the bend in the river guard wall. The arches only formed during the real ice tests, although one did form for a very short time during a test with the plastic blocks. Laboratory studies have investigated the ratio of the opening width to ice block size and incoming ice concentration that results in ice arch formation. Tatinclaux and Lee (1978) looked at the arching of both plastic and real ice blocks across an opening. Applying their work to the model configuration, it would be neces-

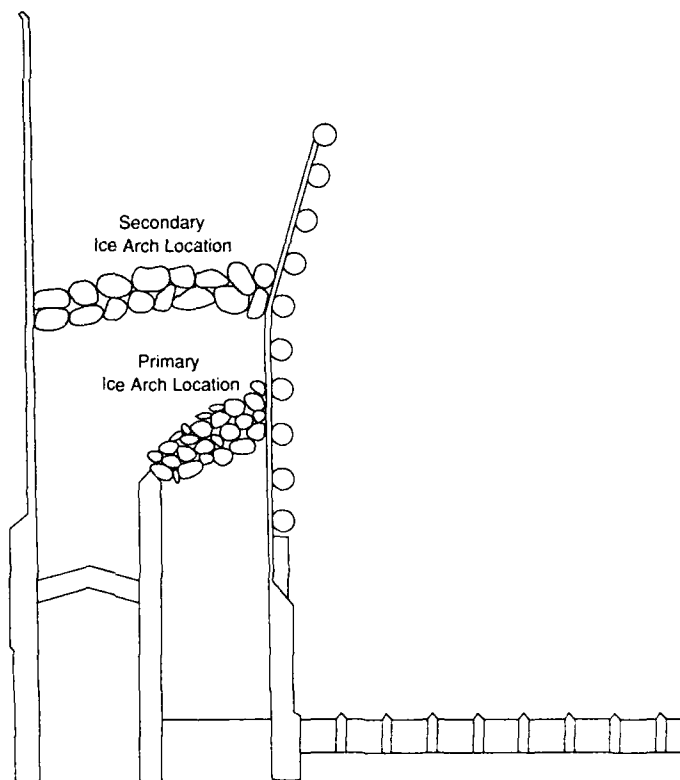


Figure 13. Typical location of ice arches formed in the upper lock approach of the model.

sary to have a plastic ice block surface concentration coming into the upper approach area of greater than 100% to cause arching. The larger size and irregular shape of the real ice pieces made arching easier. For the tests where the approach was initially clear and ice was fed into the model, concentrations were generally low enough to prevent arches from forming, even with the real ice.

As mentioned earlier, three methods were used to disrupt the arches that formed in the upper approach. The manual method would not be possible to implement in the prototype and was used initially to determine if the ice would continue to keep moving through the approach once the arch had been disturbed. Unfortunately, this was not the case, as arches would consistently reform at approximately the same location. The barge simulated river traffic that would be expected during that time of year, typically limited to single-width tows with two or three barges. The barge was slightly more effective when moving downstream, as it pushed much of the ice that was upstream of the arch into the approach. This reduced the concentration of ice remaining upstream of the approach and delayed the reformation of another arch.

Because it can be hours or days between lockages during midwinter, it was decided to test air bubblers as a means of keeping the ice arches disturbed. The arches formed at nearly the same location each time, so the placement of two high-volume point-source bubblers was sufficient to keep the ice moving through the approach. These point-source bubblers only needed to be pulsed once an arch had formed. The line bubbler described above was also tested to see if it would be useful in preventing arch formation. While it initially broke the arch, its continual operation actually imparted an upstream velocity to the surface that inhibited ice passage and assisted in reforming the arch slightly upstream of the bullnose. It was then necessary to pulse the point-source bubbler to break the reformed arch. The line bubbler was very successful in keeping ice out of the main lock gate area during tests when the approach was initially clear. The combination of the two bubblers kept the ice passing through the approach area easily and consistently.

## CONCLUSIONS AND RECOMMENDATIONS

The model study showed that a submergible lift gate located in the auxiliary lock chamber of Lock

and Dam 20 on the Mississippi River could greatly improve ice passage at the facility. A gate submergence of 3 ft (90.5 cm) proved to be sufficient to pass ice and thereby clear the upper lock approach area without a detrimental loss of pool. By using the auxiliary lock for ice passage, it becomes unnecessary to keep an ice-free channel from the upper approach to the dam or to request assistance from tows to use their propeller wash to direct ice from the upper approach toward the dam gates. This method of ice passage will be especially helpful during periods of low flow during January and February when only a ship track exists in an otherwise intact ice cover. Ice moving or being pushed down the ship track ahead of tows will be pushed into the lock approach but will be easily passed over the submergible lift gate in the auxiliary lock chamber. This will eliminate the need for separate ice lockages and reduce the potential for damage to the main lock gates.

The model tests did show that ice in the upper approach would arch across the opening and that some form of disturbance was necessary to keep the ice moving over the submergible lift gate. This could easily be accomplished by towboat traffic. There are periods during midwinter when river traffic is very light, however, when rather large accumulations could arch across the upper lock approach. The model tests showed that strategically placed high-volume, point-source air bubblers could be used to disturb the ice accumulation and keep it from arching or to disrupt arches that have already formed. The tests also showed that an air bubbler placed at a 45° angle from the end of the bullnose to the land wall in an upstream direction would act as a deflector and keep ice from entering the main lock gate area. This would reduce damage to the main lock gates and operating machinery as well as eliminate the need for any ice lockages.

It is recommended that when the submergible lift is installed, a series of field tests be conducted to determine whether ice arching is a problem in the prototype as it was in the model. If arching does occur, tests with high-volume, point-source air bubblers should be conducted to determine their optimum position in the upper approach. The use of air bubblers to keep the ice arch from forming may eliminate the need for towboat assistance altogether.

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# REPORT DOCUMENTATION PAGE

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